Spectral mapping of the accretion flow of UU Aquarii [1]

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Abstract

Time-resolved spectroscopy of the novalike variable UU Aquarii is analyzed with eclipse mapping techniques to produce spatially resolved spectra of its accretion disc and gas stream as a function of distance from disc centre in the range 3600-7000 Å. The spectrum of inner disc shows a blue continuum filled with deep, narrow absorption lines which transition to emission with clear P Cygni profiles at intermediate and large radii. The spectrum of the uneclipsed component has strong H I and He I emission lines and Balmer jump in emission and is explained as optically thin emission from a vertically extended disc wind. Most of the line emission probably arises from the wind. The spatially-resolved spectra also suggest the existence of gas stream penetration in UU Aqr, which can be seen down to $R \simeq 0.2\ R_{L1}$.

1. Introduction

UU Aquarii is a bright eclipsing novalike ($P_{orb} = 3.9$ hr) showing long-term brightness variations of 0.3 mags [Baptista et al, 1994, Honeycutt et al, 1998]. Broad-band eclipse mapping indicate that its inner disc is optically thick, with an inferred mass accretion rate of $\dot{M} = 10^{-9}\ M_\odot\ yr^{-1}$ [Baptista et al, 1996]. It was suggested to be an SW Sex star based on its relative flat radial temperature profile in the inner disc, single peaked asymmetric emission lines showing little eclipse, large phase shift between photometric and spectroscopic conjunction and orbital phase-dependent absorption in the Balmer lines [Baptista et al, 1996, Hoard et al, 1998].

In this paper we report on the analysis of time-resolved spectroscopy of UU Aqr with eclipse mapping techniques [Horne 1985] to derive spatially-resolved spectra of the accretion flow in this binary.

2. Observations and analysis

Time-resolved optical spectroscopy ($\lambda\lambda$ 3500–6900 Å) covering 5 eclipses of UU Aqr was obtained with the 2.1-m telescope at KPNO on July-August 1993 at a time resolution of 50 s. The observations were performed while UU Aqr was on its high brightness state. The spectra were divided into 226 passbands (15 Å in the continuum and fainter lines, and $\simeq$ 500 $km\,s^{-1}$ across the most prominent lines) and light curves were extracted for each passband. Average lightcurves for each passband were obtained by combining the 5 individual lightcurves. The eclipse mapping method was used to obtain a map of the

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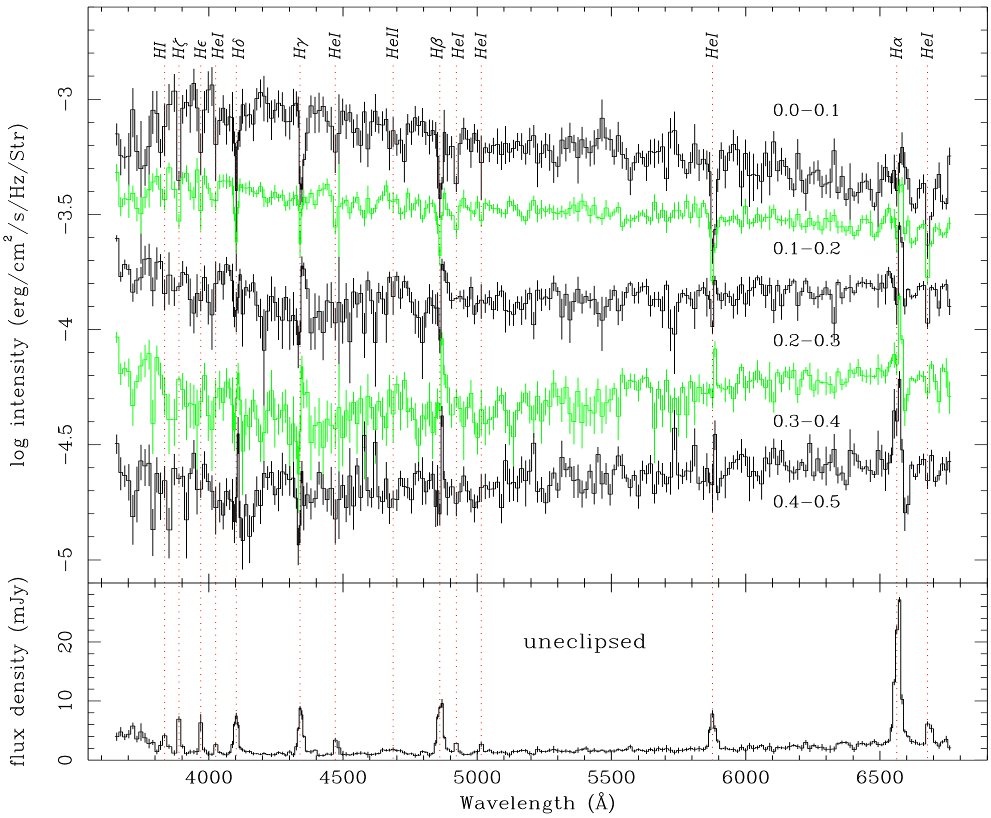

Fig. 1. Spatially resolved spectra of the UU Aqr accretion disc. The spectra were computed for a set of concentric annular sections (radius range indicated on the right, in units of R_{L1}) not including the gas stream region. The inner annular region is at the top and each spectrum is at its true intensity level. The lower panel shows the spectrum of the uneclipsed light. The most prominent line transitions are indicated by vertical dotted lines. Error bars were derived via Monte Carlo simulations with the eclipse lightcurves.

disc brightness distribution and the flux of an additional uneclipsed component in each passband. The monochromatic maps were combined to produce spatially-resolved spectra.

3. Results and discussion

Fig. 1 shows spatially-resolved spectra of the disc region in a logarithmic scale. The lower panel shows the spectrum of the uneclipsed light. The spectrum of the inner disc is characterized by a blue and bright continuum filled with deep and narrow absorption lines. The continuum emission becomes progressively fainter and redder for increasing disc radius while the lines transition from absorption to emission showing clear P Cygni profiles on all lines mapped at higher spectral resolution. The Balmer jump appears in absorption in the inner disc and weakly in emission in the intermediate and outer disc regions, suggesting that the outer disc in UU Aqr is optically thin. The change in the slope and intensity of the continuum with increasing disc radius reflects the temperature gradient in the accretion disc, with the effective temperature decreasing outwards.

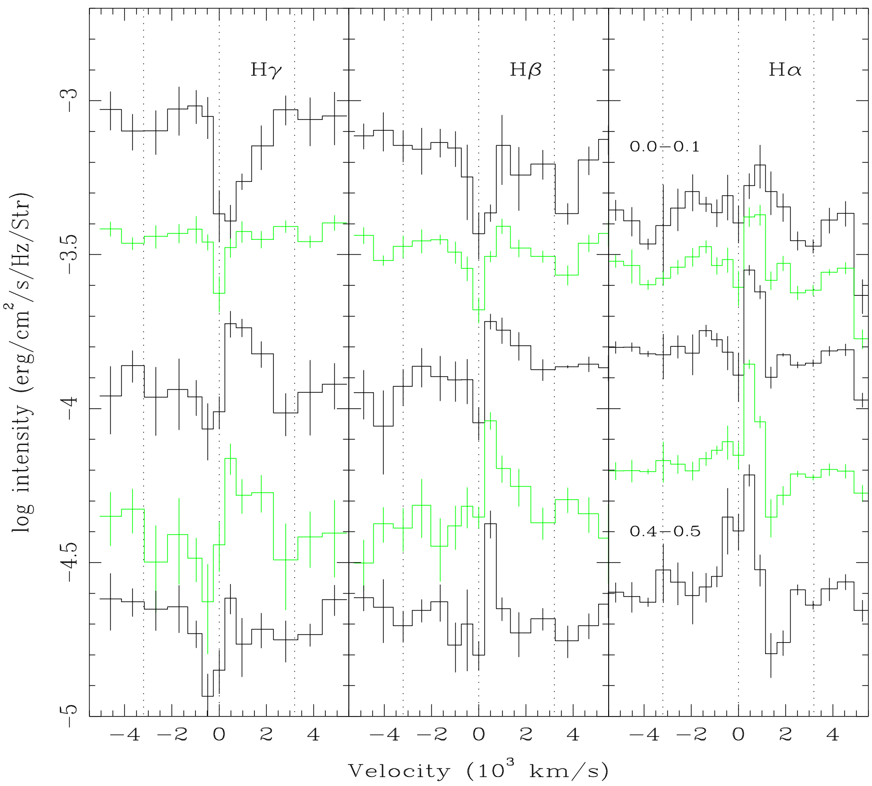

Fig. 2. Spatially resolved spectra in the Hα, Hβ and Hγ regions as a function of velocity. The notation in the same as in fig. 1. Dotted vertical lines mark line center and the maximum blueshift/redshift velocity expected for gas in Keplerian orbits around a $0.67 M_{\odot}$ white dwarf seen at an inclination of $i = 78^o$ ($v \sin i = 3200\ km\ s^{-1}$).

Spatially resolved disc spectra are shown in Fig. 2 as a function of velocity for the Hα, Hβ and Hγ lines. The absorption lines at disc center are perceptibly narrower and deeper than expected for emission from either the white dwarf atmosphere or from disc gas in Keplerian orbits around the white dwarf, and the lines show larger widths at the outer disc. This is in clear disagreement with the expected behaviour of line emission from gas in a Keplerian disc and is an evidence that most of the line emission do not arise from the disc atmosphere. On the other hand, the lines at intermediate and outer disc regions ($R \gtrsim 0.2\ R_{L1}$) show clear P Cygni profiles indicating origin in an outflowing gas, probably the disc wind.

The spectrum of the uneclipsed light shows prominent Balmer and He I emission lines (Fig. 1). The Balmer jump (and possibly also the Paschen jump) is clearly in emission indicating that the uneclipsed light has an important contribution from optically thin gas from outside the orbital plane. The fractional contribution of the uneclipsed light is very significant for the emission lines, reaching 40-60% at the Balmer lines and 20-40% at the He I lines, and decreases steadily along the Balmer serie. The difference in fractional contribution between the Balmer and He I lines indicates the existence of a vertical temperature gradient in the material above/below the disc, with the He I lines (which require higher excitation energies) being produced closer to the orbital plane. In all case, a substantial fraction of the light at these lines does not arise from the orbital plane and is not occulted during eclipse.

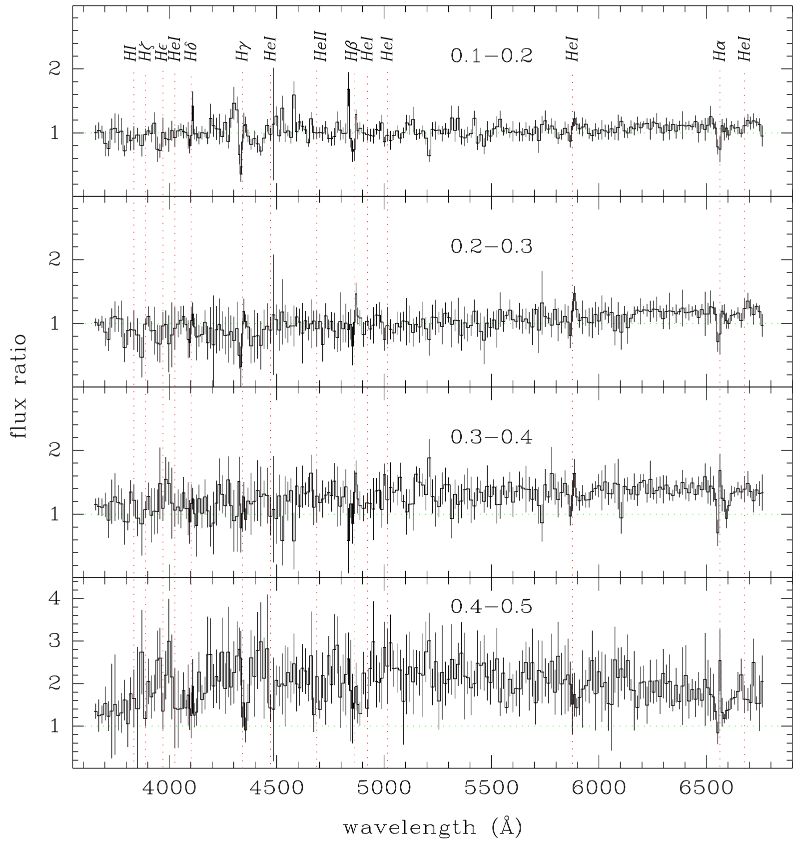

Fig. 3. Ratio of the gas stream spectrum and the disc spectrum at the same radius. A dotted line mark the unity level for each panel. The notation in the same as in fig. 1.

Fig. 3 shows the ratio between the spectrum of the gas stream region and the disc region at same radius as a function of radius. The comparison reveals that the spectrum of the gas stream is noticeably different from the disc spectrum in the outer disc regions (where one expects a bright spot to form due to the initial shock between the inflowing stream and the outer disc rim) but is also different in the inner disc regions. This result suggests the existence of gas stream penetration in UU Aqr, which can be seen down to $R \simeq 0.2\ R_{L1}$. The spectrum of the ratio becomes redder for decreasing disc radius, possibly a combination of the disc emission becoming bluer as one moves inwards and the gas stream emission becoming redder while its energy is continuously lost in the shock with disc material along the inward stream trajectory.

References

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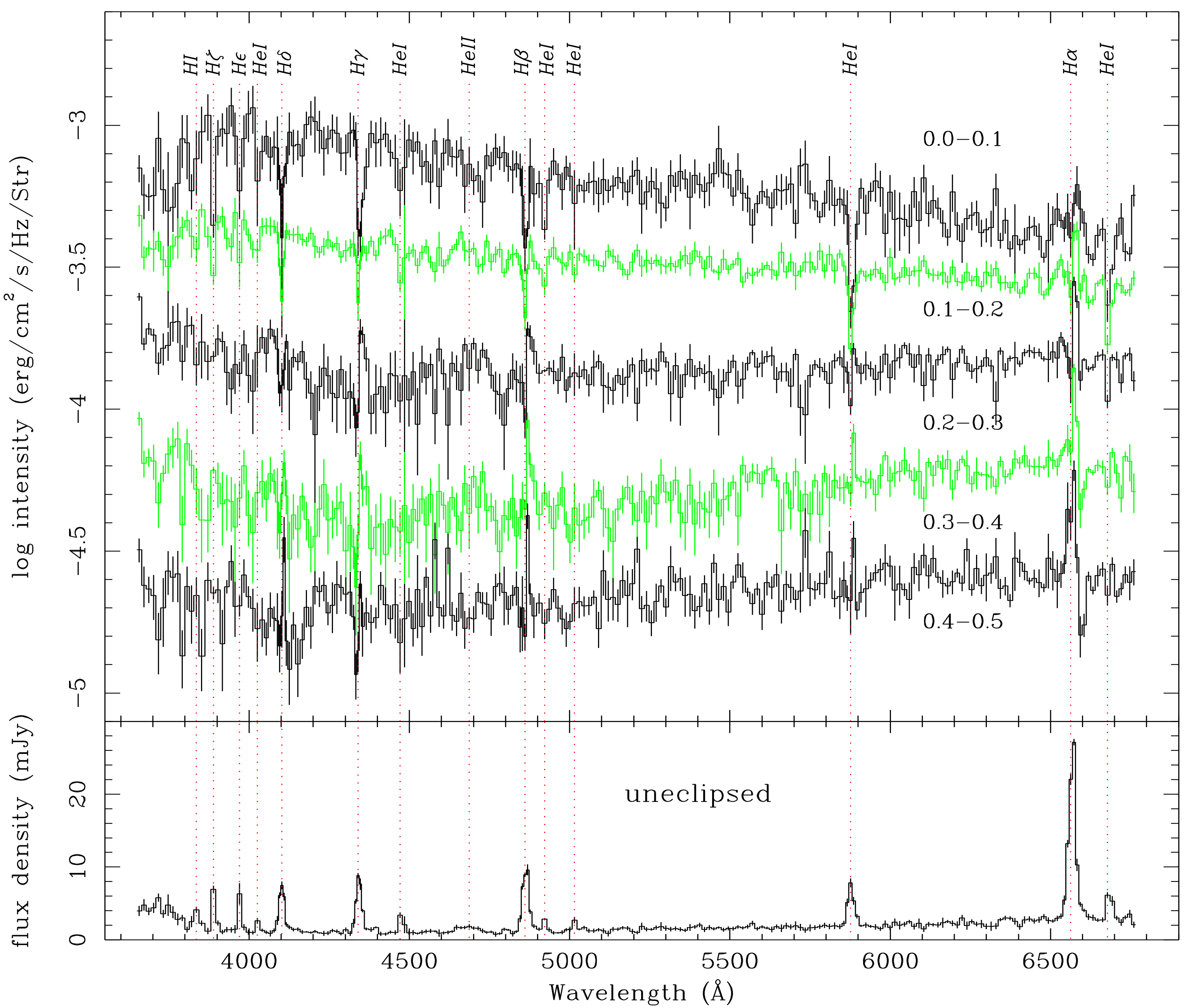
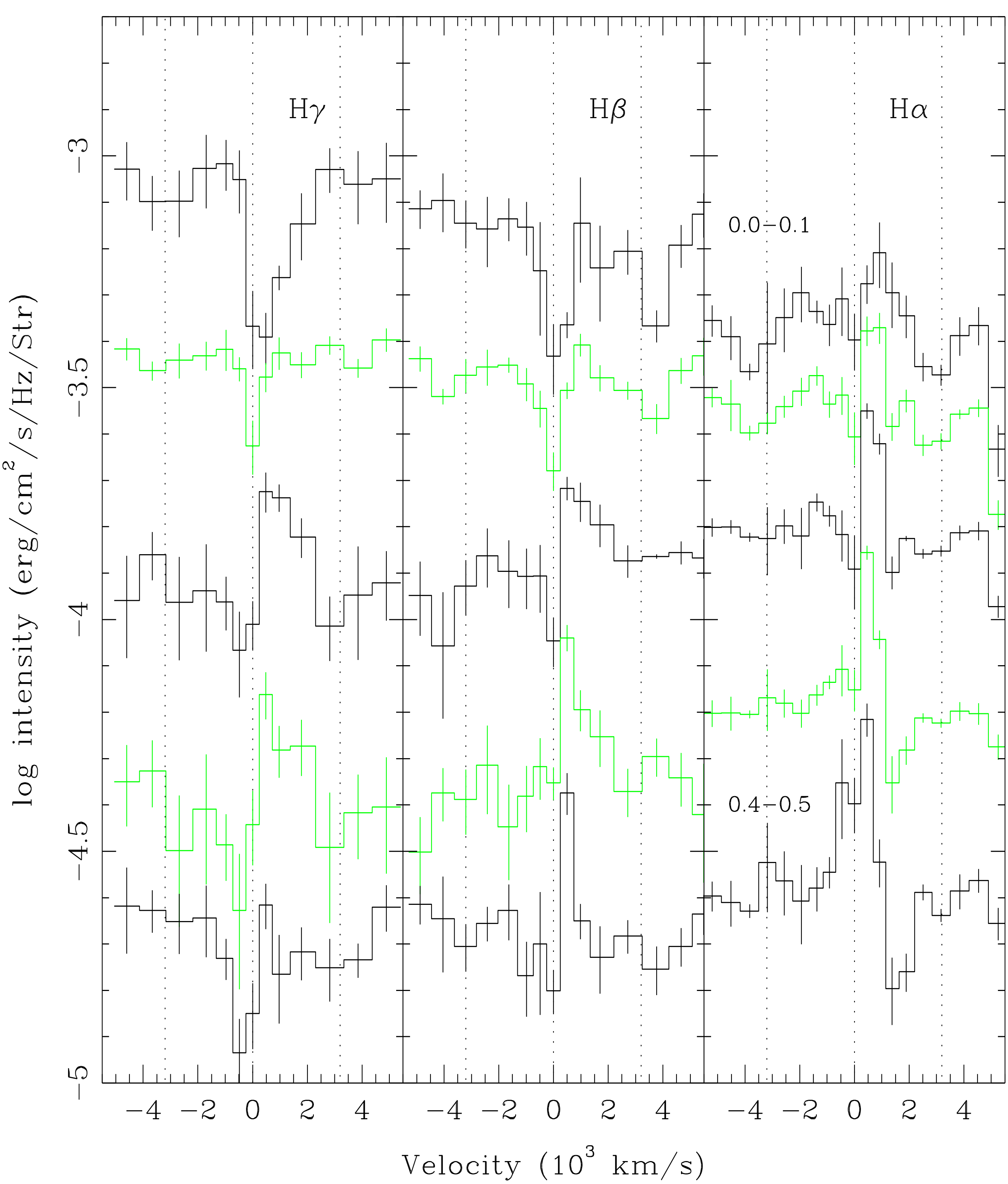
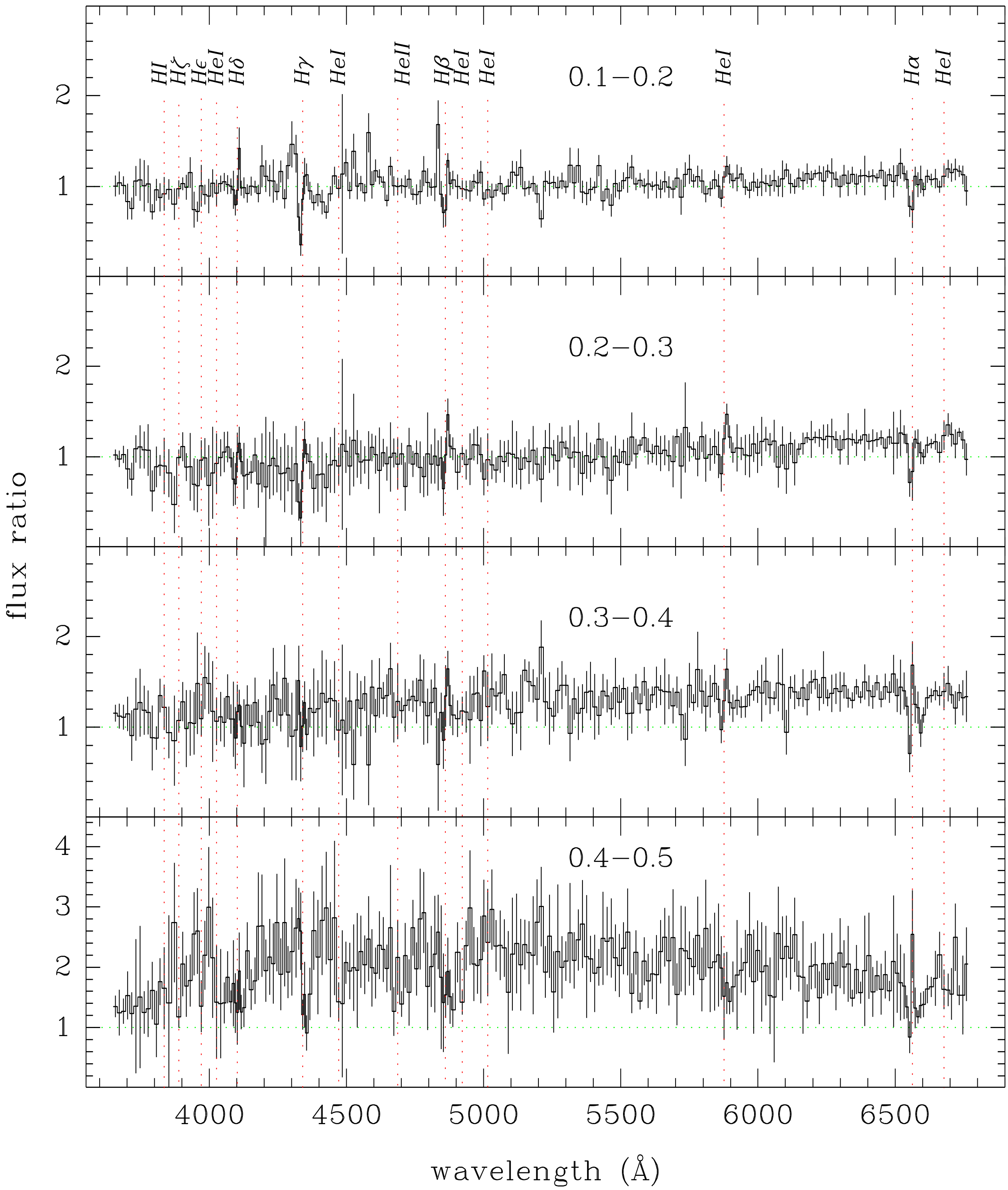

HI
Hζ
Hε
HeI
Hδ
Hγ
HeI
HeII
Hβ
HeI
HeI
HeI
Hα
HeI
0.0−0.1
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
uneclipsed
log intensity (erg/cm^2/s/Hz/Str)
flux density (mJy)
Wavelength (Å)
−3
−3.5
−4
−4.5
−5
0
10
20
4000
4500
5000
5500
6000
6500



Hγ
Hβ
Hα
0.0−0.1
0.4−0.5
−3
−3.5
−4
−4.5
−5
log intensity (erg/cm^2/s/Hz/Str)
−4
−2
0
2
4
Velocity (10^3 km/s)



HI
Hζ
Hϵ
HeI
Hδ
Hγ
HeI
HeII
Hβ
HeI
HeI
HeI
Hα
HeI
0.1−0.2
0.2−0.3
0.3−0.4
0.4−0.5
flux ratio
wavelength (Å)
4000
4500
5000
5500
6000
6500